2021 United Nations Decade
2030 of Ocean Science
for Sustainable Development

The Ocean Decade

Vision 2030 White Paper

Challenge 6

Increase community resilience to ocean hazards

Zero Draft - January 2024

unesco
Intergovernmental Oceanographic Commission

The Decade Coordination Unit of IOC/UNESCO extends its sincere appreciation to the co-chairs and members of the Working Group for their leadership and commitment in the process of drafting and authoring the draft White Paper. The draft White Paper is a foundation for diverse stakeholders to provide comments and suggestions, and its contents will be refined and complemented following the public review process. A revised version of the White Paper will be presented and discussed at the 2024 Ocean Decade Conference in Barcelona, before being finalized and published as part of UNESCO's Ocean Decade Series of publications.

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VISION 2030 WHITE PAPER

ZERO DRAFT – JANUARY 2024

CHALLENGE 6: INCREASE COMMUNITY RESILIENCE TO OCEAN HAZARDS

Enhance multi-hazard early warning services for all geophysical, ecological, biological, weather, climate and anthropogenic related ocean and coastal hazards

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Acknowledgements

To be included after the review process

Acronyms

AI	Artificial Intelligence
CSR	Corporate social responsibility
DCO	Decade Coordination Office
DRR	Disaster Risk Reduction
DT	Digital Twin
EWS	Early Warning Systems
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
ICT	Information and Communications Technology
IOC	Intergovernmental Oceanographic Commission
IOC-CD	IOC Capacity Development
ML	Machine Learning
MSP	Marine Spatial Planning
OTGA	Ocean Teacher Global Academy
SIDS	Small Island Developing States
UN	United Nations Deve
UNDRR	UN Office for Disaster Risk Reduction
UNEP	UN Environment Programme
UNESCO	UN Educational, Scientific, and Cultural Organization
WMO	World Meteorological Organization
WWF	World Wildlife Fund

1. Executive summary

This document addresses Challenge 6 of the Ocean Decade, focusing on improving coastal resilience against a range of ocean and coastal hazards. It emphasizes the critical role of coastal regions in human well-being, highlighting their susceptibility to ocean hazards, human activities, social and economic aspects, and climate change.

The paper emphasizes a holistic approach to resilience, considering hazards from both ocean and coastal perspectives. Resilience, defined as the coast's self-organizing capacity, is crucial for preserving functions under changing conditions. The need for comprehensive risk assessment and mitigation strategies, incorporating environmental, human, and socio-economic factors, is highlighted.

In the context of sustainable development goals (SDGs), coastal resilience aligns strongly with Goal 13 (Climate Action), showcasing its importance in safeguarding life and livelihoods. However, the paper points out the lack of explicit SDG targets related to coastal resilience, urging future integration into the sustainable development agenda.

The methodology for strategic ambition setting involves a detailed analysis of ocean and coastal hazards, risk assessment, risk reduction, and institutional transformation. The document outlines the components and sub-components crucial for enhancing coastal resilience, including multi-hazard evaluation frameworks, early warning systems, adaptation planning, legislative frameworks, and capacity building.

As of November 2023, Challenge 6 comprises four Programs, 24 Projects, and six Contributions, addressing specific aspects of the challenge. The analysis reveals regional disparities in leadership and representation, emphasizing the need for a more inclusive global approach.

The strategic ambition for Challenge 6 is defined through two objectives: developing people-centered multi-hazard early warning systems and designing adaptation planning strategies to enhance coastal resilience. Each objective is detailed with components and activities aimed at achieving a safe ocean where life and livelihoods are protected from hazards.

The document underscores the interdependence of Challenge 6 with other challenges within the Ocean Decade, emphasizing the importance of integration, synergies, and collaborative efforts.

Finally, the characterization of coastal stakeholder groups, Coastal Resilience Requirement Review (C3R) processes, and periodic consultation mechanisms, is proposed. Indicators are identified to track progress, ensuring a comprehensive and adaptive approach to coastal resilience planning.

In conclusion, the paper provides a thorough framework for addressing the multifaceted challenges of coastal resilience, urging global collaboration, knowledge sharing, and a sustained commitment to building a resilient and safe ocean environment.

2. Introduction

2.1. Background and context of the Challenge

Coastal regions represent areas where human well-being is most significantly affected by ocean hazards, human activities, and climate change. These influences contribute to substantial losses in human lives, economic resources, infrastructure, and natural habitats (Schinko et al 2020). Challenge 6 of the Ocean Decade aims at enhancing people-centered multi-hazard early warning services and adaptation planning for all geophysical, ecological, biological, weather, climate, and anthropogenic related ocean and coastal hazards, and mainstream community preparedness and resilience (Ocean Decade, 2023).

In this context, we embrace the definition of resilience provided by Klein et al. (1998): "The resilience of the coast is its self-organizing capacity to preserve actual and potential functions of coastal systems under the influence of changing conditions." Additionally, we adhere to the definition of hazards from UNDRR (2021): "A process, phenomenon, or human activity that may cause loss of life, injury, or other health impacts, property damage, social and economic disruption, or environmental degradation."

The focus of this paper is on the risks impacting the coastal zone. It is crucial to emphasize the need for a comprehensive consideration of hazards from both the seaward (ocean) and landward (coastal) perspectives. Additionally, it is noteworthy that ongoing discussions center around embracing the concept of adaptive capacity, particularly in the context of climate change, as the overarching framework. Resilience is identified as a key factor influencing adaptive capacity, as suggested by Klein et al. (2003). Throughout this paper, the terms "ocean" and "coastal" hazards will be used interchangeably, with a commitment to adhering to the concept of resilience.

Improving the resilience of coastal areas to a range of ocean hazards requires reconceptualizing the challenges within the framework of risk assessment and mitigation strategies. In this context, these hazards are viewed as integral components alongside vulnerability and exposure factors.

This entails a comprehensive set of data covering environmental conditions, human activities, and socio-economic assets. On one side, there is a need for fair access to this information, while on the other, there is a necessity for capacity building, awareness raising, and investment in disaster recovery, as well as planning for risk mitigation and adaptation.

Early warning to prevent disasters is crucial both at the event scale and longer-term climatic scales. The interplay between these scales helps identify longer-term changes; for instance, long-term sea level rise observations signal a heightened risk of storm surge events over annual to seasonal time scales.

2.2. Importance and relevance of the Challenge for sustainable development

In 2015, the United Nations endorsed 17 Sustainable Development Goals (SDGs) comprising 169 targets and 245 indicators, with the overarching objective of eradicating poverty, safeguarding the planet, and ensuring the well-being of people (UN, 2015). Enhancing coastal resilience brings numerous benefits, aligning with most of the SDG targets. While Goal 14 "Conserve and sustainably use the oceans, seas, and marine resources for sustainable development" is expected to be positively impacted, coastal resilience aligns most strongly with Goal 13 “Climate Action” and all its targets.

Ensuring the resilience of coastlines against both natural and human-induced hazards require the generation of sophisticated information for adaptation planning and the implementation of early warning systems. These initiatives serve as the cornerstone for improving the well-being of populations, protecting the natural environment, strengthening the resilience of coastal infrastructures, and thus formulating specific indicators related to coastal resilience across all relevant SDGs. To be noted is also the support that Challenge 6 will provide to Goal 17 through the design of responsive, inclusive, participatory, and representative risk management and decision-making across national boundaries. However, planning for adaptation and infrastructure could paradoxically encourage further development and capital investment in vulnerable areas, placing more people and economic value at risk.

It is important to note that the current SDGs lack a comprehensive acknowledgment of targets associated with coastal resilience. Going forward, the assessment and readiness for coastal risks should be more systematically incorporated into the sustainable development agenda.

2.3. Methodology for strategic ambition setting

The challenge in coastal resilience is now to devise information systems and practical methods to consider a complexity of hazards together with proper vulnerability and exposure information. The main ocean and coastal hazards are listed in Table 1. A further description of each of these hazards and their impacts is given in Annex 1.

Table 1: Relevant ocean and coastal hazards

Ocean and coastal hazard category	**Single hazard nomenclatures**
Geophysical/Geological	Tsunamis, Landslides, Subsidence, Volcanic eruptions, Coastal erosion, Earthquakes
Ocean Weather, hydrology, and climate	Tropical and extratropical cyclones and storms, Sea-level rise, storm surge, meteo-tsunami, coastal flooding, waves and wave runup, currents, marine heat waves, glacial melt, heavy rainfall and river flooding, saltwater Intrusions, droughts
Ecological	Wetland Degradation, acidification, de-oxygenation, biodiversity loss, seabed habitat loss, coral bleaching, eutrophication, connectivity
Biological	Harmful Algal Blooms, Invasive Species, aquatic diseases, nuisance blooms
Local Anthropogenic	Coastal urbanization pressures, Coastal wastewater system outflow, Marine Pollution, Overfishing, chemical spills, oil spills, nuclear waste, agricultural runoff, coastal tourism pressures, political interference and corruption, maladaptive planning

Upon the culmination of the Decade, it is imperative that coastal resilience initiatives thoroughly address three fundamental elements: Risk assessment, Risk management and reduction, and Institutional/Governance/social transformation. Each of these components is further subdivided into sub-components, focusing on pivotal aspects of risk management as detailed in Table 2. Descriptions for each element are provided in Annex 2.

Table 2: Components of Coastal Resilience and their subdivision in specific elements

Coastal resilience components	**Activities/elements**
Risk assessment	RA.1 Multi-hazard evaluation frameworks RA.2 Multi-level, multi-sector risk analysis RA.3 Exposure and vulnerability analysis
Risk reduction	RR.1 Monitoring, Forecasting and Early warning systems (multi-hazard) RR.2 Warning Dissemination & Communication RR.3 Preparedness & Response RR.4 sectoral medium to long term planning (zoning, infrastructure) RR.5 nature-based solutions RR.6 digital twins
Institutional/Governance/ social transformation	GIS.1 Marine and Maritime Spatial Planning GIS.2 Governance Framework GIS.3 Disaster recovery planning GIS.4 Equitable coastal resilience GIS.5 Government investments, financing and insurance GIS.6 Capacity building GIS.7 Corporate social responsibility

2.4. Overview of current work in the Ocean Decade

As of November 2023, Challenge 6 is the focus of 4 Programmes, 24 Projects, and 6 Contributions, addressing specific components within the challenge. Notably, there is a Decade Collaborative Centre dedicated to Coastal Resilience and another on Ocean Predictions, both of which contribute to the coordination of existing initiatives. While the majority of the 4 Programmes covering Challenge 6 span all ocean basins, the polar oceans are less represented at the Programme level. From a Project perspective, the North Atlantic Ocean is the most represented, while the Southern Ocean is the least represented among ocean basins.

Analyzing leadership, the majority of the 4 Programmes are led by European-based institutions, with one being led by an Asia-based institution. At the Project level, Europe dominates in representation, while Africa, Small Island Developing States (SIDS) and Australia in the Pacific region lack both Projects and Programmes, highlighting a significant gap for this Challenge.

The analysis identifies emerging categories among Decade Actions, with notable themes including Resilience and Adaptation, as well as Forecasting and Predictions. Remarkably, the distribution of endorsed Programmes, when compared to Projects and Contributions, is notable for its emphasis on Forecasting and Predictions.

3. Strategic ambition setting

3.1. Analysis of user needs and priorities

Understanding the specific needs and vulnerabilities of stakeholders, including residents, businesses, and public authorities, is crucial for developing resilient solutions. This information serves as the foundation for developing effective and inclusive resilience strategies that address the specific needs and challenges of all users.

Every component and element within this framework has a key role to play in formulating a thorough and efficient coastal resilience strategy. The strategic ambition for coastal resilience aids in developing plans customized to the specific ocean hazards, challenges, and priorities of the communities. This, in turn, promotes adaptive measures that strengthen overall preparedness and mitigate the impacts of ocean-related hazards, with a focus on achieving two distinct objectives.

3.2. Definition of the strategic ambition for the Challenge

Challenge 6 will contribute to the societal outcome of achieving “a safe Ocean where life and livelihoods are protected from ocean-related hazards”. This white paper promotes two strategic objectives aimed at achieving the desired outcome during the UN Ocean Decade: (i) Developing 'people-centered' multi-hazard early warning systems, and (ii) Designing adaptation planning strategies to enhance coastal resilience. Components of the each of these objectives are detailed below:

(i) People-centered multi-hazard early warning systems

Multi-hazard early warning systems address several hazards in contexts where hazardous events may occur simultaneously, cascading or accumulating over time, and considering the potential interrelated effects. An early warning system that addresses multiple hazards enhances the effectiveness and reliability of alerts by employing coordinated and compatible mechanisms and capacities. This entails the involvement of multiple disciplines to ensure the identification and monitoring of hazards are updated and accurate. People-centered warning systems include a focus on stakeholder engagement and responsibility sharing, multi-sensor observational networks, probabilistic impact forecasts, accessible communication at multiple levels through multiple communication channels and supported by technological innovations, and institutional capacity building, including strong inter-agency collaboration, as well as community level capacity building. This means that a good understanding of all the stakeholders' requirements is essential for the design of efficient early warning systems (IOC Technical Series, 2023).

(ii) **Adaptation planning strategies to increase coastal resilience**

Countries are starting to realize a long-term vision to become a climate-resilient society, fully adapted to the unavoidable impacts of climate change (Tye et al., 2020, WRI). Adaptation planning and implementation exhibit two overarching approaches, which may vary based on context and government levels: top-down and bottom-ups. Top-down methods, often employed by national governments, are scenario-driven, involving the localization/downscaling of climate projections, complex impact assessment studies, vulnerability evaluations, and the formulation of strategies. Conversely, bottom-up approaches, such as community-based adaptation, are driven by identified needs. Regardless of the chosen method, active participation from diverse stakeholders and close collaboration between research and management have been emphasized as important mechanisms to undertake and inform adaptation planning and implementation (Mimura et al., 2014).

3.2.1. Priority datasets

Early warning systems rely on a worldwide exchange of in-situ and space-based observation data, freely shared among all countries, and processed in advanced supercomputing modeling centers. Observations serve as the vital input for this system, playing a critical role in predicting events across various timescales. They are especially crucial for forecasting high-impact weather and ocean hazards within a timeframe of a few days (WMO, 2023). Few, well-known data sets that are often considered crucial for an effective multi-hazard early warning system are listed in Annex 3.

For adaptation planning, the downscaling of climate scenarios to the coast composes a high priority dataset. Such downscaling should consider hydrology, atmosphere, ocean, and impact modelling, all coupled at the relevant coastal scales for different climate change scenarios (Annex 3). Accounting for these couplings can alter long-run risk assessments and change the trajectory of adaptive capacity. This is a challenging requirement in terms of data storage and accessibility that is still not completely met in many countries.

3.2.2. Knowledge generation and sharing

Risk knowledge should be built on systematically collected data, forecasts and protocols for risk assessments. It is important that hazards and vulnerabilities specific to the region are communicated to the communities. The deficiency in disaster risk knowledge poses serious obstacles to build resilient communities. This deficiency can be due to the limited data availability, lack of interdisciplinary approaches, insufficient research and risk assessments carried out, inadequate risk communication methods and procedures to connect the research community to policymakers and to the public, and lack in understanding of climate change uncertainties into long-term risk assessments (UNDRR, 2019).

The primary initiative to enhance disaster risk knowledge involves investing in interdisciplinary and international research and development, fostering a comprehensive problem-solving approach. Continuous research yields innovative tools for data analytics, enabling the extraction of indicators and synthesis of information, as well as the creation of risk maps and accessible repositories. Ultimately, disseminating risk knowledge to all stakeholders is crucial, and this is achieved through appropriate training programs. Examples include the WMO Global Multi-hazard Alert System (GMAS), the UNESCO-IOC International Tsunami Information Center (ITIC) training program and the Ocean Teacher Global Academy (OTGA) of UNESCO-IOC.

3.2.3. Infrastructure requirements for early warning systems

The EWS infrastructure requirements for enhancing coastal resilience to ocean hazards involve a multifaceted approach. Firstly, establishing an optimal global observing network design is crucial, incorporating diverse observation platforms to monitor oceanic conditions comprehensively. This includes computational facilities and necessary resources to produce forecasts and climate downscaling.

To address the unique challenges posed by ocean and coastal hazards, an emphasis should be placed on enhanced data sharing infrastructure and data management, as well as best practices and standards.

Furthermore, the adoption of technologies such as the Common Alert Protocol (CAP), the establishment of a national standard format and mechanism for communication (particularly for individuals with different functional abilities), and the utilization of broadcast and social media for widespread dissemination are key components. The detailed infrastructure requirements for coastal resilience to different ocean hazards are detailed in Annex 4.

3.2.4. Partnerships and resources

Building coastal resilience against ocean and coastal hazards requires a collaborative and multi-dimensional approach involving partnerships at various levels, in line with SDG 17. Furthermore, collaborating with entities such as the Decade Collaborative Centres

(DCC) can provide valuable insights and resources at the global and scientific level. Nationally, engagement with Early Warning Centers, disaster risk reduction agencies, academia, and emergency managers is crucial. Partnerships with government agencies, non-profit organizations, private companies, and local communities contribute to a comprehensive strategy. The private sector's involvement, along with community engagement and donor funding, plays a pivotal role.

The engagement of local communities, as seen in initiatives like the Fisherman Field School Program, in Indonesia, ensures that the coastal population actively participates in resilience-building efforts. Community best practices such as the Tsunami Ready Recognition programme build resilient communities through awareness and preparedness strategies. Collaborative Ocean Acidification (OA) Action Plans and partnerships with organizations like the Food and Agriculture Organization (FAO), United Nations Environment Program (UNEP), United Nations Development Program (UNDP), World Wildlife Fund (WWF), and others contribute to a holistic and interdisciplinary approach. The detailed requirements of partnerships and resources for coastal resilience to different ocean hazards are detailed in Annex 4.

3.2.5. Capacity development and exchange needs

Even with effective monitoring and forecasting, ensuring that communities understand the risks and respond appropriately to warnings can be a challenge. Public awareness and preparedness empower individuals and communities to take proactive steps to protect themselves and their property, or to migrate in response to growing risks. At the community level, there is a critical need for capacity-building initiatives that empower local populations with the knowledge and skills required to understand, prepare for, and respond to ocean hazards.

This requires the establishment of networks that enable scientists, policymakers, and practitioners to collaborate, fostering a collective understanding of coastal resilience strategies. UNESCO-IOC has a well-established track record of assisting Member States in enhancing their marine environment management capabilities. Recently, a new Capacity Development Strategy (IOC-CD, 2023) has been introduced. Notably, programs like the IOC Ocean Decade Tsunami Programme are geared towards ensuring that all communities vulnerable to tsunamis are adequately prepared and resilient by 2030. The engagement of global hubs for innovation and the integration of diverse scientific fields, including oceanography, climatology, geology, and ecology, contribute to a holistic approach (WMO, 2023). Furthermore, partnerships with international organizations, such as the Food and Agriculture Organization (FAO), the United Nations Environment Program (UNEP), the United Nations Development Program (UNDP), and others, facilitate collaborative capacity-building efforts.

3.2.6. Technology and innovation solutions

Technological and innovative solutions play a pivotal role in strengthening coastal resilience against ocean and coastal hazards. This involves deploying advanced sensor networks, particularly leveraging low-cost observing technologies including beach cams, satellite technology for real-time monitoring of ocean conditions, drones, remote sensing, enabling early warning systems to detect changes such as storms and tsunamis and following F.A.I.R. (Findable, Accessible, Interoperable, Reusable) principles (Calewaert et al., 2019). Additionally, technology and innovation solutions should include the development of advanced numerical modeling, and the integration of artificial intelligence (AI) for accurate forecasting. Leveraging information technology and AI/ML capabilities is essential, as is to develop Digital Twin Frameworks for evaluating solutions before they are implemented.

A climate-resilient infrastructure is achieved through the best combination of grey and nature-based solutions, the so-called green infrastructure, and the use of smart technologies in coastal structures. A general framework for green infrastructure is being established (Chavez et al., 2021). Innovations in sand mobilization, sustainable aquaculture technologies, waste management solutions and recycling industries (for example for Sargassum) contribute to comprehensive resilience. Although these forms of infrastructure can produce short-run protective benefits, they create incentives for long-run investment in and habitation of vulnerable coastal areas.

The integration of renewable energy sources, like offshore wind and wave energy, supports sustainable power solutions, and resilient microgrid systems ensure continuous power supply during and after hazards. Utilizing emerging ICT technologies, through for example cellphone apps, ensures effective communication of early warnings, particularly in vulnerable communities. The detailed requirements of technology and innovation solutions for coastal resilience to different ocean hazards are detailed in Annex 4.

3.3. Integration, synergies, and interdependencies with other Challenges

Challenge 6 is inextricably linked to all the other challenges of the Decade. By enhancing multi-hazard early warning services and adaptation planning, communities can be alerted about potential pollutants to mitigate the impact on human health and ocean ecosystems addressing Challenge 1. In the realm of risk assessment, Challenge 6 will play a role in safeguarding and managing coastal ecosystems, aligning with the objectives of Challenge 2.

Timely alerts on weather, climate, and anthropogenic-related ocean hazards enhances safety at sea. Improved safety supports fishing communities and may complement efforts to promote sustainable fishing practices, which connects with Challenge 3. Fish farming and marine aquaculture is developing frameworks for specific early warning systems (Montes et al., 2023). Early warning services and adaptation planning for ocean hazards are crucial for ensuring the safety of maritime activities and businesses. Enhancement of these services addresses Challenge 4 directly by ensuring the sustainability of ocean economic activities. Understanding the ocean-climate nexus as well as how climate change influences ocean hazards, which is in line with Challenge 5, will give inputs to climate adaptation planning and early warnings on changing coastal extremes.

Challenges 6 and 7 complement each other in building resilience by providing the necessary observational foundation for effective early warnings. Integration of real time ocean observations into high fidelity numerical modelling for Digital Twins contributes to Challenge 8.

Challenge 9 emphasizes the importance of capacity development, serving as an integral component of both multi-hazard early warning systems and the adaptation solutions for coastal resilience. Enhanced awareness facilitated by early warnings encourages the required behavioral changes, ensuring that adaptive measures align harmoniously with establishing a sustainable relationship with the ocean, thereby addressing Challenge 10.

4. Milestones and indicators

To progress toward the two major outcomes for coastal resilience outlined in Section 1 and 2, three milestones must be established:

1. **Characterize relevant Coastal Stakeholder Groups**

   Identify coastal stakeholder groups residing in several typologies of coastal environments, among others: a) Coastal Cities and Ports, b) Delta and Estuaries, c) Small Islands, d) Transitional coastal waters and e) Iced coastlines.

2. **Establish a Coastal Resilience Requirement Review (C3R) process** tailored to the specific needs of each stakeholder group:

   a) For coastal cities and ports: address urban planning, infrastructure, and community resilience.

   b) For delta and estuaries: focus on ecosystem preservation, water management, and infrastructure resilience in these dynamic environments.

   c) For small islands: emphasize adaptive strategies, sustainable development, and community engagement given the unique challenges faced by small island communities.

   d) Transitional coastal waters: address conservation and protection actions, nature-based solutions and sustainable food production;

   e) Iced coastlines: focus on coastal erosion, loss of biodiversity and changes in economic activities.

3. **Plan Periodic Consultation Mechanisms:** establish formal and periodic consultation mechanisms to gather insights from stakeholders and derive indicators of resilience that are interconnected with Sustainable Development Goals (SDGs) targets and the C3R process. This includes a) defining key indicators of resilience specific to each typology of coastal environment; b) aligning these indicators with relevant SDGs targets/indicators to ensure a comprehensive and integrated approach; c) establishing regular consultations to gather feedback, assess progress, and adapt strategies based on evolving needs and challenges.

This structured approach aims to address the diverse needs of coastal stakeholder and ensure that resilience planning is tailored to the unique characteristics and challenges of the coastal environment typology. An initial scheme for the establishment of C3R is shown in Fig. 1. Such process could grow out of a close collaboration between the new Decade Collaborative Centers and Offices created by the Decade to harmonize the work of the UN decade Programs and Projects.

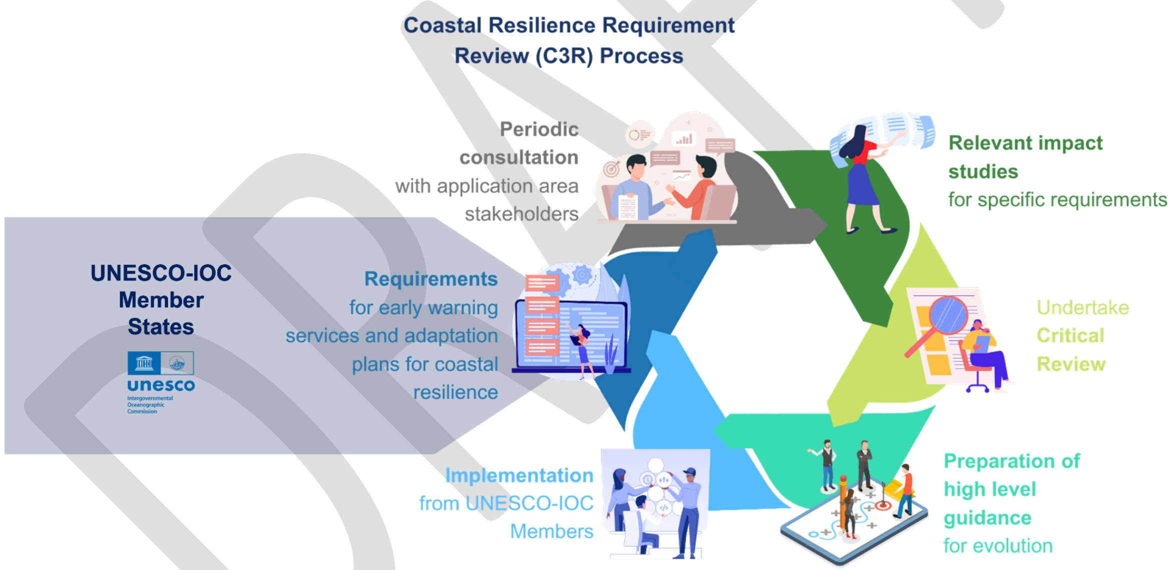

Figure 1: The Coastal Resilience Requirement Review (C3R) process

4.1. Indicators to track the achievement of the strategic ambition

Indicators need to be formulated to track the progress of the Coastal Resilience Requirement Review process. These may include, but are not limited to, indicators that demonstrate the improvement of knowledge related to the identification and comprehension of coastal multi-hazard, encompassing cascading effects (section 2.2.2); indicators for best practices in data sharing for early warning systems (section 2.2.3);

indicators of the advancement in best practices and standards for risk reduction (section 2.2.3); indicators of successful capacity building and educational practices (section 2.2.5); indicators reflecting the successful development of international partnerships (section 2.2.4); indicators of changes in institutional and legislative frameworks supporting coastal resilience.

These metrics offer a comprehensive perspective on the advancements made in the Coastal Resilience Requirement Review. They encompass various facets, including enhanced awareness of hazards, stakeholder engagement, data quality, adherence to timelines, review outcomes, implementation of recommendations, capacity building, monitoring and evaluation, community involvement, budget management, and alignment with policies. The ultimate task involves fine-tuning these indicators according to the goals and objectives during each periodic assessment of the Coastal Resilience Requirement Review process.

Annex 1: Description of Ocean and Coastal Hazards

The listed hazards refer to Table 1 in the text.

Single hazard nomenclature	**Description**	**Impacts**
Tsunamis	Large sea waves caused by underwater earthquakes, volcanic eruptions, landslides	Coastal flooding, widespread destruction, loss of life, property damage, disruption and loss of employment and livelihoods.
Landslides	Landslides are the downward movement of rock, soil, and debris on a slope or inclined surface. This movement can range from slow, gradual soil creep to rapid and catastrophic rockfalls or debris flows.	Loss of land, property damage, habitat destruction.
Subsidence	Subsidence refers to the gradual or sudden sinking or settling of the Earth's surface, often due to various geological or human-induced factors.	Structural damage to infrastructures and increased vulnerability to sea-level rise, flooding, habitat loss
Volcanic Eruptions	Volcanic eruptions can lead to various volcanic hazards, including lava flows, pyroclastic flows, ashfall, and volcanic gases and can trigger tsunamis	Destroys infrastructure, alters landscapes, can produce flash floods and coastal erosion, tsunamis, disruption and loss of employment and livelihoods.
Coastal Erosion	Gradual and rapid loss of land due to the natural action of waves, currents, wind and sargassum,	Loss of land, property damage, habitat destruction
Earthquake	An earthquake is a seismic hazard that produces ground shaking and tsunamis if occurring in the ocean.	Structural damage to buildings and infrastructure, sinking or tilting of structures

Tropical and extratropical cyclones and storms	Tropical and extratropical cyclones are powerful atmospheric systems characterized by organized circular wind patterns around a low-pressure center.	Heavy rainfall, storm surges, and high winds, causing flooding, destruction of coastal infrastructure and coastal erosion.
Sea-level rise	Gradual increase in sea level globally due to melting ice caps, thermal expansion, salinity contraction and changes in air-sea interactions fluxes. In coastal limited ocean regions, changes in circulation causing changes in transport across the open boundaries might be also a component of sea level rise.	Coastal erosion, inundation, saltwater intrusion
Storm-surge	Storm surge refers to the abnormal rise in seawater level during a storm, primarily caused by the onshore winds and low atmospheric pressure associated with a hurricane or other intense storm systems.	Flooding, infrastructure damage, loss of life, property damage, disruption and loss of employment and livelihoods.
Meteo-tsunami	It is a type of tsunami-like wave that is caused by meteorological factors such as rapid changes in atmospheric pressure, severe thunderstorms, or other intense weather-related phenomena.	Flooding, infrastructure damage, loss of life, property damage, disruption and loss of employment and livelihoods.
Coastal flooding	Excessive rainfall, storm surge, strong winds or tidal fluctuations causing inundation of coastal areas	Property damage, displacement, loss of infrastructure, loss of life, disruption and loss of employment and livelihoods.
Waves and wave runup	Large waves generated by storms or strong winds can contribute to coastal inundation and erosion. Wave runup is the movement of waves up onto the shoreline.	They can produce erosion, coastal flooding, saline Intrusion, habitat changes, property damage, onshore and off-shore infrastructure damage, sediment availability changes, etc.

Currents	Currents are the result of turbulent viscosity and density gradients inside the water column, which adds to the Stokes drift. Anomalous currents in coastal areas could be due to changes in winds, river discharges and air-sea thermal and water fluxes. Important are also rip currents that are caused primarily by wave breaking	Coastal erosion and deposition, habitat disruption, disrupt ecological connectivity, navigation and shipping challenges, livelihood loss and disruption, coastal drowing.
Marine heat waves	It refers to a prolonged period of excessively warm sea surface temperatures.	Coral Bleaching, Ecosystem Disruption, Fisheries Decline, Ocean Acidification, disruption of marine ecosystems, biodiversity changes, harmful algal blooms, fisheries, and weather patterns, disruption and loss of employment and livelihoods.
Glacial Melt	The melting of ice in coastal areas is a significant aspect of climate change, particularly in regions where glaciers, ice sheets, sea ice and permafrost are present	Ecosystem Disruption, Sea Level Rise, coastal erosion, infrastructure stability
Heavy rainfall and river flooding	Large precipitation anomalies created by intense cyclones can lead to large river discharge inundating the land areas and affecting the seaward water quality as well creating large stratification at the surface and an increase in harmful algal booms	Coastal Erosion, Saltwater Intrusion, Infrastructure Damage, Erosion of Coastal Habitats, Water Quality Issues: Disruption of Transportation, Increased Risk of Storm Surges: Health Risks due to contaminated waters, disruption and loss of employment and livelihoods.
Saltwater Intrusion	Movement of seawater into rivers and freshwater aquifers, compromising drinking water and soil quality	Drinking Water Contamination, Agricultural Impact, Ecosystem Disruption, Infrastructure Damage, fisheries production

Droughts	Droughts are prolonged periods of abnormally low precipitation levels, leading to water shortages	Water scarcity, saltwater intrusion, ecosystem stress (marshes and estuaries, etc), agricultural losses, fish habitat loss, wildfires, human migration.
Wetland Degradation	Loss of natural buffers like mangroves, marshes, and coastal forests that protect against storm surges and erosion	Reduced storm surge protection, habitat loss
Harmful Algal Blooms	Rapid growth of harmful algae that can produce toxins, leading to fish kills and contamination of seafood.	Fish kills, shellfish contamination, human health, disruption and loss of employment and livelihoods. significant costs attached to the removal from beaches. In the Caribbean large influxes of Sargassum forced evacuations of coastal populations
Coral Bleaching	Stress-induced loss of colour in coral reefs due to rising sea temperatures, which affects marine ecosystems and fisheries	Biodiversity Loss, Coral Mortality, fisheries yields decline, disruption and loss of employment and livelihoods.
Invasive Species	Introduction of non-native species that can disrupt local ecosystems and damage coastal habitats	Biodiversity Loss, Habitat Degradation, Economic Losses, Altered Food Chain
De-oxygenation	Deoxygenation of marine waters refers to the reduction or depletion of dissolved oxygen levels in the ocean and it results from various factors, including increased water temperatures, excessive nutrient runoff leading to algal blooms and subsequent decomposition, and changes in ocean circulation patterns.	Loss of biodiversity, disruptions in food webs, and the creation of hypoxic or anoxic zones, fish kills.

Acidification	Increased carbon dioxide absorption by oceans, affecting marine life and coral reefs	Fish kills, shellfish contamination, Increased CO2 Emissions, harm to marine life, disruption and loss of employment and livelihoods.
Biodiversity loss	Coastal ecosystems, including mangroves, salt marshes, coral reefs, and estuaries, are incredibly biodiverse and provide numerous ecological services.	Ecological services not available, disruption and loss of employment and livelihoods.
Seabed habitat loss	Seabed habitat loss refers to the degradation, alteration, or complete removal of the physical and biological features that constitute the seafloor environment.	Biodiversity decline, altered ecosystem structure, fisheries decline, increased vulnerability to storms, impaired water quality, decreased carbon sequestration
Eutrophication	Excessive nutrients causing overgrowth of algae	oxygen depletion, dead zones, ecosystem imbalance, habitat degradation, fish kills, human health risks
Connectivity	Interconnectedness of habitats, ecosystems, and the movement of species within and between marine regions	Loss of connectivity: genetic isolation, ecosystem fragmentation, vulnerability to climate change, etc. Increase of connectivity: invasive species spread, disease transmission, sediment and pollution transport changes, sea level vulnerability
Aquatic diseases	Illnesses and health conditions affecting organisms living in aquatic environments	Population decline, altered food web and impacts on aquaculture, genetic changes, etc.
Nuisance blooms	Rapid and uncontrolled proliferation of non-toxic algae in aquatic environments, causing undesirable effects	oxygen depletion, ecosystem and economic activities disruption

Coastal urbanization pressures	Improper land use and construction near coastlines leading to increased vulnerability to hazards	Habitat destruction increased vulnerability to hazards
Coastal wastewater outflow	Release of treated or untreated wastewater into the coastal environment	Water quality degradation, harm to aquatic life, eutrophication, pathogen contamination, sedimentation
Marine Pollution	Discharge of pollutants into coastal waters, harming marine life and impacting human health	Water contamination, harm to marine life and ecosystems, disruption and loss of employment and livelihoods.
Overfishing	Depletion of fish stocks, disrupting marine ecosystems and affecting livelihoods of coastal communities generated by Illegal, Unreported and Unregulated (IUU) practices.	Depletion of fish stocks, disruption of marine ecosystems, declining food security and nutritional-wellbeing, disruption and loss of employment and livelihoods.
Chemical spills	Accidental or deliberate release of hazardous substances or chemicals into the marine environment.	Water contamination, toxicity to marine life, habitat damage, human health impacts, etc.
Oil spills	Accidental or deliberate release of oil into coastal waters, causing environmental damage to marine life and habitats	Environmental Damage, Water and beach pollution, disruption and loss of employment and livelihoods.
Nuclear Waste	Intentional or accidental release of radioactive waste into marine environments near coastlines.	Radioactive contamination, human health risks, long term persistence
Agricultural runoff	Movement of water, containing pollutants from agricultural activities, from land to coastal ecosystems	nutrient enrichment leading to eutrophication, pesticide contamination, harmful algal blooms, pathogen transport, etc.

Coastal tourism pressures	Overdevelopment and mass tourism leading to habitat destruction, pollution, and disruption of natural coastal processes	Environmental Degradation, Erosion and Infrastructure Damage, Water Pollution, Loss of Cultural Identity, Loss of income to fishermen and beach vendors due to privatization of beaches
Political interference and corruption	Manipulating decisions for personal or political gain and abuse of power for personal enrichment, undermining ethical standards.	Poor planning and decision making, unsustainable coastal development, illegal resource exploitation, etc.
Maladaptive planning	Ineffective strategies that worsen vulnerability to climate change, disregarding ecosystem dynamics, and social impacts.	Increased vulnerability to ocean and coastal hazards

Annex 2: Activities for risk assessment and management

The following subsections list the needs in terms of products and services for each of the activities in Table 2.

RA.1 Multi-hazard evaluation frameworks

A multi-hazard evaluation framework means: an approach that considers more than one hazard in a given place (ideally progressing to consider all known hazards) and the interrelations between these hazards, including their simultaneous or cumulative occurrence and their potential interactions. (Gill and Malamud, 2014). De Angeli et al. (2022) has defined 5 steps for the multi-hazard framework: 1) identification of hazards and their interactions; 2) multi-hazard modelling; 3) analysis of the spatial and temporal evolution of the impacts from the hazards; 4) identification of impact interaction types; 5) the multi-hazard risk assessment.

These five steps require:

1) Observational evidence of both hazards and impacts, satellite and in situ measurements;
2) Merged topography and bathymetry data set;
3) Modelling (numerical models of, and AI applied to) the hazards and impacts, with a numerical/digital representation of them, including hazard mapping and forecasting
4) Toolbox to represent dynamical interactions and overlaps between hazards
5) Visualization tools, cloud computing and friendly user interfaces

RA.2 Multi-level, multi-sector risk analysis

Here we focus on quantitative or probabilistic risk analysis, that aims at understanding societal resilience to environmental, climate and economic extreme events and long-term changes. To faithfully represent societal systems across spatiotemporal scales, multi-sector system representations need to account for dynamic and endogenous interactions between sectors. Lastly, we need to consider the uncertainties in human behavior and factor this in the multi-level risk analysis.

Each coastal area of interest should analyze first the type of human activities occurring there and the need is to have well organized data sets on socio-economic indicators for each sector of relevance. These data need to be matched with environmental data at similar spatio-temporal scales. In addition, the analysis should be multi-level, in other words targeted to different groups, from policy makers to the public at large. Priority should be given to the sector and the hazard that most influence coastal resilience.

Climate change risk in coastal areas also requires climate downscaling of environmental variables that may affect sectorial productivity and damages. Downscaling climate change projections at the scale of coastal urban development, sewer water management, etc. And in a multi-hazard context, this is a very urgent need. Some solutions exist at the moment (Whetton et al., 2012), but the UN decade should put effort in coastal climate downscaling and the infrastructure needed to make the data accessible.

This analysis requires:

1) Human activities data sets, economic indicators across sectors and their socio-economic interactions at high spatial-temporal resolution
2) Climate projection downscaling to the coasts in a multi-hazard context
3) Data accessibility and best practices for data dissemination

RA.3 Exposure and vulnerability analysis

Socio-ecological systems worldwide are increasingly subjected to hazards of natural and anthropogenic origins, we call this exposure. Vulnerability measures the "resilience" capacity of the human population and infrastructure to the exposure to natural and man-induced hazards. Increasing resilience and reducing the vulnerability of social–ecological systems (SES) so that they can withstand shocks and long-term changes is crucial.

Thus, for this element of the risk assessment the need to quantify coastal hazards frequency and amplitude specifically for each coastal area and their potential interactions with weaknesses across relevant socio-economic sectors. A thorough understanding of the vulnerability causing factors and coping capabilities is required through a vulnerability framework analysis. The latter is to be done at a local, community level and it requires definition, identification, classification and prioritization of population, economic sectors and infrastructures weaknesses.

For this element we need:

1) Identification of hazards through mapping as done for the previous elements;
2) population demographic data, societal exposure (major employer sectors, transportation access, disabilities, language, ethnicity, race, education, etc.)
3) Land usage and future usage plans, water and wastewater facilities, roads, ports, bridges,
4) economic sectors fragility;
5) Development of on-demand tools for the assembly of relevant data and indices for the vulnerability mapping

RR.1 Monitoring, Forecasting and Early warning systems (multi-hazard)

Monitoring, forecasting, and early warning systems for coastal hazards aim at reducing risks, enhancing preparedness, and improving response to a range of potential threats. The products of the early warning system should be based on robust scientific principles and supported by reliable technology to (i) monitor and identify hazards promptly, either in real-time or near real-time, and (ii) provide forecasts and warnings continuously 24 hours a day, throughout the entire year. Continuous monitoring and detection of various coastal hazards requires near real-time data from various observation networks. Reliable observation networks are the backbone of early warning systems. Continuous data from observation networks provide decision-makers with precise and up-to-date information on the state of the coastal environment.. With this knowledge, authorities are empowered to make well-informed choices pertaining to prioritizing vulnerable areas, issuing evacuation directives, allocating emergency resources, and devising strategies for effective responses. Effective monitoring often requires the collaboration among multiple agencies, organizations, and countries, necessitating data sharing and cooperation.

The modelling tools simulate various coastal hazards, such as tsunamis, storm surges and sea-level rise, based on available data. These models consider different scenarios and provide insights into the potential impacts on coastal communities and ecosystems. Based on the analysis and modelling scenarios, early warning systems are designed to take decisions, and issue alerts and notifications to relevant authorities and communities in advance of impending hazards.

For this element we require:

1) Optimal notional global network design consisting of a mix of observation platforms/types
2) Developing and maintaining a monitoring infrastructure
3) Data collection systems with advanced technology and resources
4) Enhanced data sharing
5) Development and maintenance of advanced numerical modelling and AI-based forecasts
6) Ensure to take on board the groups working on common tasks so that the observation networks can address multi-hazard requirements
7) Identify hotspots from a multi-hazard perspective for prioritization and redundancy of installations
8) Multi-purpose observation networks and platforms
9) New use cases of existing observation systems and development of new sensors
10) Promote technologies for possible co-deployment of sensors with met-ocean moorings to enhance network coverage and maintenance
11) Big data Analytics, High Performance Computing and Processing techniques for real-time data analysis and forecasting
12) Keep track of the new technology developments in observing systems and include them in the update of the plan
13) Advocacy with all stakeholders including Private Industry, Intergovernmental organizations and Scientific Expert Teams for rapid development and implementation of new observational technology

RR.2 Warning Dissemination & Communication

After detection and monitoring of impending threat warning center authorities must take a decision to disseminate the information to the relevant disaster management officials who are responsible for issuing evacuation directives. To provide decision-makers with the knowledge they need to make informed and effective decisions during the threat, a standard operating procedure-based Decision Support System is an effective tool. It bridges the gap between raw data and actionable insights, ultimately enhancing warning dissemination and communication.

Effective communication of warnings is essential to reach those in vulnerable situations and facilitating national and regional coordination and information exchange. Multiple communication channels are necessary to ensure as many people as possible are warned, to avoid failure of any one channel, and to reinforce the warning message. According to Sakalasuriya et al. (2022), it is important to consider formal and informal sources, such as religious and disaster management officials, to more effectively mobilize evacuation during an emergency. It's imperative to convey concise messages with easy-to-understand, practical information. This will enable organizations and communities to respond effectively, safeguarding lives and livelihoods.

Most countries maintain warning systems for single hazards which are rarely integrated. To support redundancy, consistency, and accessibility, the focus must be on multi-hazard early warning alignment by linking hazard-specific systems. This applies to resources, capacity, information, SOPs, etc. There are numerous standards and protocols used by alerting authorities to transmit warnings. The machine-readable XML format - Common Alerting Protocol (CAP) is an international standard format for emergency alerting and public warning, developed by the International Telecommunication Union and promoted by a number of agencies. To support standardization in communication across all hazards countries should adopt CAP, as a tool for minimizing the overheads of using multiple channels.

For this element we require:

1) Collaborative development of warning information and Standard Operating Procedure (SOP) prerequisites involving nodal agencies for warning and disaster management officials, and relevant stakeholders
2) Use of information technology and AI/ML capabilities
3) Understanding the target audience (culture, education, capacity, abilities, inclusiveness etc.)
4) Develop impact-based warning content
5) Redundant mechanism in receiving and disseminating warning and communication
6) Promote Common Alert Protocol (CAP) and training to the staff

7) National standard format and mechanism for warning and communication for People with Different Functional Abilities
8) Effective use of Broadcast and Social Media
9) Media Training for warning centre staff and Training for Media Broadcaster and Social Media Influencers
10) Adopt new/emerging technologies (Digital and Communication)
11) Use of multichannel dissemination alerting including "implementation of geo-located mobile early warning services using cell-broadcast and/or location-based SMS"

RR.3 Preparedness & Response

Even with effective monitoring, ensuring that communities understand the risks and respond appropriately to warnings can be a challenge. Public awareness and preparedness empower individuals and communities to take proactive steps to protect themselves and their property. It is essential to provide training on interpreting hazard information, using warning systems, and implementing emergency protocols for communities to respond effectively. Disaster management planning need to be more people-oriented with focus on last-mile outreach, with a shift in focus from early warning dissemination to communication through impact-based forecasting and warnings.

By prioritizing disaster management planning and adaptive strategies, coastal regions can enhance their capacity to respond resiliently to emergencies, protecting lives, property, and ecosystems. When an early warning is issued, it is a call for actors on the ground, including national and local authorities to activate their respective response plans to reduce the impact of the hazard. A well-prepared and practiced response plan minimizes the responding time and ensures efficient and effective utilization of resources.

Communities need to be ready to respond 24 x 7 to all coastal hazards. For example, programmes like “Weather Ready” and “Tsunami Ready” identify the areas that need to be improved and actions to be taken as “indicators”. The indicators include comprehensive and tailored response plans and the capacity in place to manage the event.

For this element we require:

1) Identification of Hazard Zones and development of Inundation Maps
2) Enhancing GIS capacity within each country
3) Data and information for evacuation maps (sensitive and critical infrastructures)
4) Community participatory approach in evacuation maps
5) Establishment of multiple communication channels, including traditional means and protocols among all stakeholders, including local authorities, emergency services, community leaders, and the public

6) Implementation of robust early warning systems that can quickly alert coastal communities
7) Adaptation of education resources to the local context (language, culture, local threat, risk, etc.)
8) Involvement of local communities in the emergency response planning process
9) Identification and allocation of necessary resources such as personnel, equipment, shelters, medical supplies, and transportation to effectively respond and to optimize resources
10) Development of specialized multi-hazard awareness education resources for people with Different Functional Abilities
11) Engagement and inclusion with People with Different Functional Abilities (association, communities, authorities, etc.)
12) Share best practices and lessons learnt on oceanogenic hazards education and awareness in school curricula
13) Engage with other global frameworks on School disaster risk reduction
14) Identify and Include the location and number of at-risk communities in the national response plan
15) Preventive evacuation arrangement (evacuation decided by authority)
16) Preparation of inventory of the available resource and capacity for emergency response within at risk community
17) Conducting training sessions and drills involving all relevant parties to ensure that everyone understands their roles and responsibilities
18) Emergency response plans for local threats based on natural warning signs in the absence of official warnings can save lives
19) Encourage self-evacuation (escape / run) arrangement (evacuation decided by individuals)

RR.4 sectoral medium to long term planning (zoning, infrastructure),

To enhance the ability of coastal regions to withstand and recover from various hazards, we need medium to long-term designing strategies. Assessment and quantification of exposed people, services (e.g. hospitals) and critical infrastructure (e.g. electricity and water work, quality of building stock) should be planned zone-wise. Zoning involves dividing coastal areas into different sectors based on their vulnerability to hazards and potential land uses. This information guides where development should be restricted or adapted and most importantly to prepare emergency response plans. Also, the infrastructure development planning to focus on designing and constructing physical structures that can withstand hazards and support the well-being of coastal communities.

The medium term planning may be for 1-5 years and should contain a thorough assessment of coastal hazards and vulnerabilities, identify high-risk areas, critical infrastructure, vulnerable communities, establishment of early warning system, redundant communication channels, upgradation of critical infrastructure to be more resilient against coastal hazards (e.g., elevating buildings, reinforcing bridges), implementation of nature-based solutions like mangrove restoration to provide natural barriers and capacity building. Whereas long-term (5-20 years) planning to focus on developing comprehensive land use plans that account for hazards and vulnerabilities, implement zoning regulations to guide safe development and protect high-risk areas, establish, or revise policies and regulations related to coastal disaster management and ensure that disaster risk reduction is integrated into broader development policies. These long-run plans also must acknowledge the new incentives for development in vulnerable coastal areas when effective short-run protective measures are put in place. Some tradeoffs between short-run and long-run risk may be inevitable.

For this element we require:

1) Mapping for all relevant hazards, as well as of any compounding risks, at local level in both rural and urban areas and coastlines
2) Inventories of critical infrastructures inside the inundation area (accessibility e.g., airport, ports) (telecoms, energy, food, fresh water & medical supply)
3) Ability to identify the vulnerable groups within the identified zones
4) Number of residents and visitors with their fluctuation (daily and seasonal) within the zones
5) Identifying and prioritizing economic assets
6) Identifying and prioritizing the built environment
7) Identifying and prioritizing the natural environment
8) Retrofit existing infrastructure to meet climate change challenges (e.g., rising sea levels, increased storm intensity)
9) Incorporating green infrastructure and smart design principles for long-term resilience
10) Incorporating lessons learned from past disasters into ongoing planning
11) Evaluate impacts to critical infrastructure and secondary risks associated with hazard and risk management solutions to be considered to increase resilience
12) Flexible, adaptive approaches to infrastructure can be used to reduce the costs of building climate resilience, given the uncertainty about the future
13) Assessment of vulnerabilities of key economic sectors at national to local levels
14) Regular assessment of the effectiveness of disaster management efforts and adjustment/upgradation of strategies as needed
15) Collaboration with neighboring/similar countries to share information, resources, and best practices for coastal disaster management

RR.5 Nature-based solutions

According to various reports, coastal forests such as mangroves ameliorated the death tolls and damage caused by the December 2004 tsunami in the Indian Ocean (Kerr and

Baird, 2007, Chatenoux and Peduzzi, 2007). Nature-based, flexible or innovative approaches to climate-resilient infrastructure may be cheaper than traditional approaches. Building or enhancing protective structures like seawalls, breakwaters, and dunes to shield against coastal erosion, storm surges, and tsunamis. Nature-based solutions in the oceans and coastal areas are vital to strategies to strengthen disaster resilience. For example, coastal vegetation such as mangroves, salt marshes, and dune systems act as natural barriers that absorb wave energy, reducing the impact of tsunamis, storm surges and erosion. The oyster reefs and seagrass beds stabilize sediments and promote water filtration, improving water quality and reducing the risks of erosion.

Nature-based solutions for climate change adaptation involve the conservation, sustainable management and restoration of natural or modified ecosystems to help societies adapt to climate change, such as restoring mangrove forests or conserving coastal wetlands. Beach nourishment, involving the replenishment of sand and sediment, can restore and enhance beaches, creating natural buffers against storm damage. Living shorelines, which integrate native plants and materials, offer a sustainable alternative to traditional seawalls, safeguarding coastlines while maintaining ecological balance. Wetland restoration projects can not only protect against flooding but also enhance biodiversity and carbon sequestration, contributing to climate change mitigation.

Global standards are being developed for nature-based solutions, such as the IUCN Global Standard for nature-based solutions, which emphasizes that these solutions are designed to be climate-resilient and take uncertainties in climate predictions into account. Incorporating nature-based solutions such as marshes to defend against erosion and hybrid strategies such as seawalls or dikes combined with nature-based ones, into the design of coastal infrastructure can increase at-risk communities climate change adaptability and provide coastal flood protection.

For this element we require:

1) Assessment of site to identify vulnerable areas and determine the most suitable locations for implementing nature-based solutions
2) Strategies to develop ecological designs that mimic natural coastal ecosystems, integrating features such as mangroves, dunes, seagrass beds, and oyster reefs
3) Scientific basis to ensure that chosen nature-based solutions are appropriate for the specific coastal conditions and disaster risks
4) Involve local communities, experts, and relevant stakeholders in the planning and decision-making process to ensure that solutions align with local needs and cultural considerations
5) Solutions should adhere to relevant environmental regulations
6) Long-term monitoring programs to assess the effectiveness of implemented solutions

7) Integrate nature-based solutions into broader coastal development plans and policies to ensure their sustained resilience and effectiveness against future oceanogenic disasters
8) Promotion of “green belts” and “buffer zones” to avert future catastrophes

RR.6 Digital twins

A digital twin (DT) is a virtual representation of a real process or object with a two-way connection between the two. This means that changes in the real-world object are incorporated into the DT near real-time, and adapting the boundary conditions of the DT can illustrate various potential 'what-if' scenarios of the real object (Ossing et al., 2023).

Digital twins are built on interactive digital platforms, which allow for continuous observation and simulation of supercomputing tasks to recreate present and future scenarios. The first and essential upgrade to realize the Digital Twin is continuous data assimilation enabling a close to real-time synthesis of data products and a set of numerical models that update the model forecast as new data are continuously assimilated into the model. For example, a Digital Twin for GEOphysical extremes (DT-GEO) is a European project that aims to analyze and forecast the impact of tsunamis, earthquakes, volcanoes, and anthropogenic seismicity. Digital twin (DT) is one of the most promising technologies for multi-stage management which has great potential to solve the above challenges (Yu and He, 2022).

For this element we require:

1) Accurate and up-to-date geospatial and environmental data, including oceanographic, meteorological, and topographical information, to create a realistic digital representation of the coastal area
2) Integrate data from various domains, including physical, biological, and ecological data, to capture the complexity of coastal ecosystems and their interactions
3) Utilize high-resolution models that accurately simulate hydrodynamics, wave propagation, sediment transport, and other relevant processes to capture the behavior of oceanogenic disasters
4) Integrate real-time data streams from sensors, buoys, satellites, and monitoring stations to provide continuous updates on changing conditions, facilitating timely responses
5) Incorporate advanced simulation techniques and high-performance computing facilities that can accurately predict the behavior of coastal systems
6) Develop the capability to simulate and analyze different disaster scenarios in real-time, including storm surges, tsunamis, and sea level rise
7) Collaboration among experts from fields such as coastal engineering, oceanography, ecology, data science, and risk assessment to ensure a comprehensive digital twin solution

8) Design user interfaces that present complex data and simulations in an easily understandable and accessible manner
9) Provide access to decision makers to manage the events and get the feedback to improve its accuracy and predictive capabilities over time
10) Involve local communities, stakeholders, and authorities in the design and utilization of the digital twin

GIS.1 Marine and Maritime Spatial Planning

The European Commission's (2011) has advanced the promotion of Maritime Spatial Planning (MSP) to facilitate efficient and effective regulation of the sea, its coastal areas and the protection of marine ecosystems. Concerns around the marine environment stem from the anticipated increased exploitation of the marine resource and associated competing and conflicting uses (Lloyd et al., 2013). We consider this as the proper framework for governance of improved coastal resilience.

UNESCO-IOC has developed an MSPglobal International Guide on Marine/Maritime Spatial Planning (UNESCO-IOC, 2021) and here we will report their findings in terms of needs.

The Guide mentions that the following spatial data are needed to characterize physical oceanographic conditions: Bathymetry, Currents, Waves, Temperature, and salinity. Furthermore, coastal risk assessment data are required, such as: coastal erosion, flooding areas, sea level rise, hurricane winds, storm surges.

In addition to these physical and risk data, MSP requires also to identify:

1. Location of the different components of the maritime use (e.g. people; vessels; anchors; moving gears; installed infrastructure) at horizontal and vertical dimensions.
2. Importance of the use’s functional components: the relevance of each component to perform the activities of the maritime use, i.e. division into most likely and rarely employed components.
3. Operational characteristics of the use: How a use’s operational characteristics can create conflicts through either exclusion zones (permanent or temporary; including buffer zones), or interference with the success (including safety) of another use.
4. partial constraints: The degree of flexibility to select operating areas, i.e. site-dependence, to avoid conflict with other uses, as well as the degree to which the use’s operating area is regulated by a governmental institution that determines where, how and when it may operate.

Finally, indicators are suggested to be defined for context, inputs, outputs, process and outcomes. Indicators have numerous uses and potential for improving MSP in terms of simplification, verification and communication. They can help to monitor and assess conditions, forecast changes and trends (such as providing early warning information), as well as evaluate the effectiveness of the planning decisions.

GIS.2 Governance framework

In 1982 the UN adopted the Law of the Sea Convention that has resolved several important issues related to ocean usage and sovereignty, such as:

- Established freedom-of-navigation rights
- Set territorial sea boundaries 12 miles offshore
- Set exclusive economic zones up to 200 miles offshore
- Set rules for extending continental shelf rights up to 350 miles offshore
- Created the International Seabed Authority
- Created other conflict-resolution mechanisms (e.g., the UN Commission on the Limits of the Continental Shelf)

UNEP also created The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities. It is the only global intergovernmental mechanism directly addressing the link between terrestrial, freshwater, coastal and marine ecosystems. Furthermore, The UNEP Regional Seas Programme implements region-specific activities, bringing together stakeholders including governments, scientific communities and civil societies. These Multilateral Environmental Agreements are governed by their own meetings of the Contracting Parties.

The International Maritime Organization (IMO) is the key United Nations institution for the development of international maritime law. Its main task is to create a fair and effective, generally accepted and implemented legal framework for the shipping industry.

The Food and Agriculture Organization (FAO) supports countries in incorporating the agriculture sector, including fisheries and aquaculture, into national level governance frameworks on disaster risk management (legislation, policies and plans). FAO also supports the development of Disaster Risk Preparedness and Response Plans for the agriculture sector including fisheries and aquaculture.

There is still little recognition of the needs for products/services from these Conventions and Organizations to increase community resilience against ocean hazards, except for the UNEP regional seas programme where planning for monitoring of pollution from land and offshore activities has been organized from many years (from 1974).

Thus, the needs from these legislative frameworks are the same as for risk assessment and reduction.

GIS.3 Disaster recovery planning

Normally, generating interest in disaster response planning and management is difficult. Ashrafi and Alkindi (2022) suggest some priorities for the current tsunami response planning and management efforts which we have now modified to consider multi-hazard disaster response: (1) there should be no early warning systems without national actions plans; (2) there should be investment in preparing communities at risk; (3) early warning systems should be multi-hazard as much as possible; (4) there should be a consideration of disaster-induced famine and disease outbreaks in response planning.

In addition, WMO (20XX) suggests that forecasting in general should be developed in terms of impact forecasting. Translated to the oceanographic context, forecasts and warnings should be designed to express the expected impacts related to ocean hazards and to provide detailed information down to the individual, activity or community level.

The needs for an effective disaster recovery planning in the future years might be:

1) prepare communities at risk that could be sustainable over generations, based upon a post-event analysis of natural multi-hazard impacts;
2) improved planning for different risk scenarios based on different impacts or combinations of impacts occurring; a Digital Twin approach could be useful when natural and socio-economic data are brought together;
3) better contingency planning (best, reasonable worst-case and most likely outcomes);
4) information about level of confidence in the forecast that would convey additional information for better decision-making (a more informed risk assessment);
5) assist countries to install low-technology but simple and effective local flood-warning equipment. This might coincide in the strengthening of the community science actions that are developing in the Decade
6) a systematic community partnership program should be established between the impacted and other communities according to an agreed plan. Such inter-community partnerships could give private citizens and organizations leading roles, give the rebuilding effort a human face, and divide it into units that are comprehensible and accessible to donor communities.
7) Follow closely the development of UN DRR activities

GIS.4 Equitable coastal resilience

Consideration of all communities in planning for disaster recovery or coastal resilience is a key factor. Incorporating consideration of social justice and equity is however still at the beginning and it requires much research work and stakeholder consultation around practical problems. Learning from several experiences in US, the emerging needs are:

1) Track equity across time and space, recognizing the need for comparison while acknowledging the local context
2) Collect examples of “coastal settlement” changes occurred in the past and analyze the socio-economic elements characterizing them;

3) Evolve methods to assess if a specified element of risk assessment and reduction is making a difference in advancing equity while building coastal resilience?
4) identify relevant data, integrating data, and conducting analysis to ensure the community is considered
5) Consistently collect data to capture demographic shifts

GIS.5 Government investments, financing and insurance

Economic costs of disasters remain high and are likely to increase in the future. Nevertheless, economic assessments face both technical and policy challenges. The Secretariat to the UN International Strategy for Disaster Reduction (UNISDR) commissioned several studies on the economics of investing in DRR (https://www.preventionweb.net/understanding-disaster-risk/business-case-for-DRR).

An initial paper has been posted that analyzes the full benefits of climate change adaptation investments, divided into three types of dividends. It shows that the benefits that accrue even when the anticipated disaster does not occur are often larger than the "avoided losses" that accrue when disaster does strike. This is important since it shows that the benefits of adaptation investments are often larger than assumed, and don't always rely on the probabilities of disaster risk.

Here the need is threefold:

1) Accumulate adequate data for the costs of disaster recovery for coastal resilience, that data also to be defined in detail;
2) Start socio-economic modelling of early warning systems and quantify their positive impact;
3) Contribute to the Priority Action 3 and the Sendai Framework for DRR 2015-2030 on the basis of the Decade plan for Coastal resilience in view of ocean hazards

GIS.6 Capacity building

Developing capacity in coastal resilience is essential at both institutional and community levels, particularly for nations in the global south. Building capacity within institutions and local communities across various aspects of resilience, including Early Warning Systems (EWS), is crucial.

Interfacing with the large UNESCO-IOC training and general educational activities is mandatory here. Four are the relevant existing activities:

1) The Ocean Teacher Global Academy (OTGA): OTGA aims to build equitable capacity related to ocean research, observations and services in all IOC Member States by delivering training courses on a range of topics addressing the priority areas of the UN Decade of Ocean Science for Sustainable Development and the

2030 Agenda and its SDGs as well as supporting the implementation of the IOC Capacity Development Strategy. **The audience here are scientists and ocean professionals.** The need here is to develop specific modules for Coastal resilience that will incorporate the ocean hazards risk assessment, reduction and governance.

2) The Expert Team on Operational Ocean Forecasting System (ETOOFS) as part of GOOS. They elaborated the first guide for ocean forecasting systems, available here: https://www.goosocean.org/index.php?option=com_content&view=article&id=293&Itemid=424. The audience is the scientific community at large and the operational oceanographic national systems. Here the need is to add the coastal perspective and the early warning systems in a multi-hazard pespective.
3) The Tsunami information center training material: http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1558:training-materials&catid=1062&Itemid=2256. The audience is tsunami early warning organizations at national level. Here there is a need to add multi-hazards monitoring and forecasting as for ETOOFS.
4) The Unesco-IOC Ocean Literacy program (https://oceanliteracy.unesco.org/?post-types=all&sort=popular) with the goal of creating an ocean-literate society able to make informed and responsible decisions on ocean resources and ocean sustainability. Here we could point out the need of stronger links with the ocean hazards community.

GIS.7 Corporate social responsibility

Corporate social responsibility (CSR) in the private sector working for coastal solutions, is a critical element of responsible business practice, providing strategic economic advantages while helping to minimize environmental damage. This field related to coastal resilience is very young, in fact we do not know of any example to enhance CSR in risk assessment and reduction.

Environmental degradation, industrial accidents and the impact on the livelihood of local coastal communities have many examples of negative impacts that have manifested in the past. Nuclear power plants delivery of radioactive material after tsunamis (Fukushima accident), oil spills from reservoirs located very close to the sea (Lebanon accident) and oil spill rigs (Gulf of Mexico accident), coastal erosion due to hard protection solutions for beaches, coastal pollution due to wastewater treatment plants, to mention only few, show that CSR for coastal resilience is lacking behind other sectors.

Data needs here could be coming initially from socio-economic surveys to evaluate acceptance of the existing solutions by private and public organizations.

Annex 3: Priority Datasets

To support risk assessment and management a complex set of data from satellite, in situ platforms and numerical models are required. Here is an initial list of essential thematic data sets.

Thematic data set	**Parameters**
Meteorological Data:	Real-time weather data from both instruments and numerical models, including temperature, humidity, wind speed, and wind direction, precipitation and atmospheric pressure.
Seismic and Geophysical Data:	Earthquake data from seismometers, strong motion accelerometers to detect seismic activity, Global Navigation Satellite System (GNSS) data to monitor ground deformation due to earthquake, volcanic activity, landslide etc.
Hydrological Data:	River discharge for water levels and flow rates from gauges and from hydrological modelling, and soil moisture data to assess landslides and flooding risk. Dissolved chemicals in water and their loading, sediment mass balance at the river-estuary interface with the coastal ocean.
Oceanographic Data:	Sea level data to monitor for potential tsunamis, Sea level from in situ, satellite and numerical models for storm surges, wave buoy data and numerical model outputs for high-waves and swells etc., sea temperature and salinity, and marine current data from satellite, in situ and numerical oceanographic models to track heat anomalies and transport of pollutants and sediments. Biogeochemical variables from satellite, in situ and numerical models including phytoplankton, PH, oxygen, dissolved and particulate chemical species.
Human activities	Population density and distribution data, Vulnerability and exposure data, Vessel traffic density, Marine Protected Area domain extension and number, aquaculture and mariculture sites, fishing intensity, housing stock, transportation, energy, public safety, wastewater treatment, and educational infrastructure.

Seabed habitat Data	Seagrass meadows, mangroves, and coral covers
Bathymetry, terrain and geological data	Digital elevation model data combining terrain and bathymetry, seabed sediment grain size, substrate classification and sedimentation rates, submerged landscapes
Climate downscaled scenarios	Downscaled IPCC climate scenarios for all hydrological, meteorological, ecosystem and oceanographic thematic variables listed above.
Human health	Water quality monitoring to detect microbial contamination, monitoring for pollutants such as heavy metals, pesticides, and industrial chemicals, harmful algal blooms monitoring, mosquito and tick surveillance, monitoring and reporting of waterborne, foodborne, and other communicable diseases in coastal communities

Annex 4: Member inputs

Member	Overview of the Coastal / Ocean hazards to be considered	Analysis of user needs and priorities	What kind of technology & innovation solutions would be required by 2030	What are the partnerships and resource requirements	Interdependency with other Decade Challenges/Any additional inputs/Comments
Enrique Alvarez Fanjul	**Storm-Surge** **High Waves**	● Improving observations ● Modelling, forecasting and Early warning ● Community awareness and preparedness and mitigation measures ● Cross cutting priorities (Climate change adaptation, Ocean literacy and Capacity building)	● Low-cost observing technologies ● Promoting wide data utilization ● Satellite altimeters ● F.A.I.R principles, Best practices, global standards and QC for data management ● Promote Research in Ocean forecasting and modelling (ensemble, coupled) ● Promote advanced techniques for data analysis and accessibility (AI, GPU, Cloud computing) ● Low-cost techniques for downscaling climate information ● Ocean literacy for Decision makers ● New ways of Capacity Building	● Global and Scientific level (DCC) ● National (Early Warning centres and disaster risk reduction and emergency managers)	● Decade challenges (1, 2, 5, 6, 8 and 10) are interconnected ● Global coordination among: ○ Ocean Observing DCO ○ Data sharing DCO ○ Ocean Prediction DCC ○ Coastal Resilience DCC ○ Regional DCCs ○ CoastPredict ○ DITTO ○ GEMS-Ocean ○ Foresea
Andrea Valentini	**Storm Surge**	● Hazard mapping and risk assessment	● Early warning systems ● Science and technology to improve	● Government agencies, non-profit organizations,	Addressing the underlying factors that make

		● Effective operational early warning system ● Emergency plans, procedures and regulations ● Upgrade and implement infrastructure	the accuracy and timeliness of early warnings (AI, Remote sensing, drones, satellites, supercomputing) ● Digital Twins ● Share and link databases ● Develop numerical models ● Provide access to existing resources ● Continuous monitoring including Citizen participation	private companies and the community itself	communities vulnerable to storm surges, such as climate change, sea level rise, coastal development, poverty, inequality, and urbanization
Loreto Duffy-Mayers	**Sea-level rise, Coral Bleaching, Ocean Acidification, Increased Storm Intensity, Marine Pollution, Sargassum, Invasive species, Mangrove and salt pond destruction**	● Community Protection (Early warning systems) ● Sustainable Livelihoods (sustainable practices in fisheries, tourism and other ocean dependent sectors) ● Conservative efforts ● Education and Awareness.	● Ocean monitoring system ● Eco-engineering ● Sustainable Aquaculture Technologies ● Waste Management Solutions ● Sargassum Industries	● Regional ● International ● Private sector ● Community involvement ● Donor funding	● Interdisciplinary approach ● Harnessing traditional knowledge ● Long-term vision
Mitch Harley	**Coastal Erosion**	● Enhanced monitoring (baseline, coastal change, forcing conditions and anthropogenic interventions	● Accurate and timely Early warning systems ● Monitoring through Satellite monitoring, citizen science, digital earth initiatives	● States and National governments	

		● Modelling, forecasting and Early warning	● Innovations for sand alternatives		
Dwikorita	**Hydrometeorological and Tectonic**	● Effective translation of Technologies to benefit users like fishermen and coastal communities ● Advancements in Ocean modelling and Observation technology ● Engagement of private sector ● Promoting sustainability ● Systematic observation ● Innovation in Science ● Data Integration (Volcano activities) ● Community awareness and preparedness	● Impact-based Early warning systems ● Ocean Literacy programs (Fisherman, climate, earthquake and tsunami field schools) ● Adaptation strategies (community preparedness) ● Collaboration for data exchange, tsunami preparedness	● Local government, NGOs, private sectors, academics and coastal communities ● Engagement of local communities (eg. Fisherman Field School Program) ● People-centered systems and processes	● Integration other global frameworks to ensure mutual benefit
Martina Müller	**Tsunami**	● **Assessment of c**ommunity needs and priorities through a “think resilience” approach ● Community awareness to tsunami risks ● Access to early warning systems ● Early action if tsunami hits ● Strong coastal defence mechanisms	● Risk assessments (to be substantially refined, comprehensive methodologies, non-seismic events) ● Tsunami detection systems (modern detection technologies, remote sensing, GIS and space-based technologies)	● National, regional and inter-regional collaborations ● Harness UN’s convening role ● UN Secretary-General’s Early Warning for All initiative ● Partnerships with science and technology community and	

		• Well-grounded policies and frameworks • Community resilience plans encompassing all relevant sectors (e.g. health, education and tourism) • Needs and priorities of different populations (e.g. women, the elderly and children) • Key underlying disaster risk drivers: poverty, inequality and vulnerability	• Early warning systems (use of emerging technologies and support to governments, particularly to reach vulnerable communities such as SIDS and LDCs; promoting People-centered and inclusive early warning systems) • Early action (community awareness and preparedness) • Coastal defense systems (breakwaters, seawalls, flood levees and nature-based solutions) • Risk governance (policies and frameworks, Tsunami Ready Recognition Programme, participatory scientific frameworks, and methods in line with SF-DRR)	private sector to integrate scientific research and private sector innovation into policy-making processes • Global hubs for innovation to accelerate solutions	
Alessandra **Burgos**	**Coastal resilience to all hazards**	• Rural communities that are prone to islanding must have action plans • Local knowledge invaluable	• Balance between innovation and building on existing knowledge and resources	• Unified system to address ocean hazards (gulfree.org for Gulf of Mexico)	• ECOPs should have more connections across disciplines and regions to collaborate on

		• Easy access to research and data for local emergency managers and governments • Funding • Resources must be accessible and user-friendly	• Collaborative hub for experts • Co-production of knowledge • Central clearinghouse of data for various stakeholders • Clearinghouse should also feature real-time information on hazards • AI and data scrapping tools	• Well-coordinated network for more effective response to ocean hazards	research, policy development and the sharing of resources and tools
Iris Monnereau	**Tropical Cyclones**	• **Need for** rapid restoration of activities in fisheries and aquaculture to continue providing livelihoods and food security • Operational early warning systems and shock-responsive social protection • Disaster Risk Preparedness and response plans at national and local level • Improved understanding of risks, strengthened access to climate information, comprehensive baseline information, scalable community	• Early warning systems adapted to the local communities in the Global South • Low-cost technologies for developing EWS and communicating alerts • Parametric insurance • Support for Ecosystem based approaches • Development of Hazard-resilient communities, especially in Global south	• National and community (Early Warning centres and disaster risk reduction and emergency managers at the national and community level) • Regional, National, and inter-regional collaborations • UN collaboration to improve Early warning systems • Partnerships between science and technology, governments, IGOs, communities, CSOs, NGOs and the private sector	

		risk management solutions ● Hazard risk mapping and risk assessment for impacts tropical cyclones ● Governance frameworks (legislation, policies, plans) in place for disaster , procedures, process and funding ● Funding needs		● People-centered systems and processes	
David Cabana	**Climate change**	● Developing pragmatic science integrating multiple disciplines and multiple knowledge systems. ● Climate services adapted for the final user adapted to local conditions for locally led transformation (adaptation and mitigation). ● Provide greater resolution to the role of transdisciplinary bottom-up locally-ledcommunity-level relevant climate information and services.	● Authentic engagement (engage diverse groups) ● Artful and engaging communication (effective communication of scientific findings) ● Advocating and motivating transformation (Governance systems with well-established boundaries) ● Governance for social-ecological systems (Implementation of improved, comprehensive and integrated management plans)	● Interdisciplinary collaboration and partnerships among scientific disciplines, local communities, governments, NGOs and private sectors ● Amalgamation of diverse scientific fields (oceanography, climatology, geology and ecology) ● Integrated solutions that transcend local scales ● Integration of climate change knowledge in coastal management	Each challenge is intricately linked to the others, and working independently across these challenges should be discouraged.

		• Integrating climate models and scenario discovery techniques • Developing multi-hazard and cross-sectoral methodologies integrated in the National Adaptation Plans (NAPs) • Bridge gaps between science, policy and practice through novel approaches • Collaborative problem solving and working across organizational, sectoral and institutional boundaries • Connect with networks for information sharing and access to specialized knowledge and climate services • Increase the engagement with private sector	• Anticipation in governance • Lived experiences and values • Working towards global goals, transformation, and sustainable coastal futures • Recognizing the correlation between social innovation and sustainable development goals • Integrating social innovations highlighted in scientific literature	• Collaborative and interdisciplinary efforts	
Martin Smith	**Coastal resilience for all hazards**	• Coastal system as a coupled human-natural system • Safe development paradox			

		• Spatial scale, Spatial Heterogeneity and Spatial Spillovers • Compound Stressors • Mitigation, Evacuation and climate Signal			
Joel Kamdoum	**coastal erosion, sea level rise, coastal flooding, loss of coastal and marine biodiversity, marine pollution, and urbanization**	• Reliable early warning systems • Robust emergency responses • Access to timely and accurate information • Education and awareness • Comprehensive and actionable science-based recommendations (legal frameworks, spatial planning and zoning policies and regulations) • Adequate knowledge to conservationists on coastal hazards to prioritize sustainable environmental protection, conservation or restoration • Industries' needs to be centered around sustainable practices • Researchers need funding, cutting-edge	• Multifaceted technological and innovative approaches (bioengineered structures and low-impact defenses for mitigating coastal erosion) • Real-time satellite monitoring, adaptive elevated structures, and advanced climate-resilient agricultural tools are needed to combat climate change • Marine protected areas and sustainable fisheries management with real-time access • Marine pollution: advanced waster management systems and oil remediation technologies • Coastal urbanization need smart coastal planning, development of advanced green	• Local, national, international partnerships • Scientific collaboration amongst researchers and research institutions • Partnering with private sectors, NGS and alliances of communities • Funding • Access to new technologies • Real-time data and information to be coupled with educational resources for decision making, public awareness and capacity building	• The addressed hazards are interconnected with other challenges 2,3, 4, 5, 7, 8, 9 and 10. • Collective approach is required

		technology and strong collaborative networks to unearth solutions Communities need increased awareness and understanding of the hazards and impacts	infrastructure and establishment of digital platforms (IoT, AI, ML, virtual and augmented reality)		
Hellen J. Kizenga	**Overfishing and coastal habitat destruction**	• Diversified livelihoods (Alternative income generating activities) • Improved fishing technology (sea-worthy vessels, smart gear technique and remote sensing technology) • Social services and infrastructures • Storage and markets • Empowerment of community management of the resources	• Fish stock assessment-based technologies • Internet of Things (IoT) based smart fishing gears and vessels • Advanced remote sensing technology • Blockchain and traceability systems • Properly established Marine Spatial Planning • Others: monitoring with AI, established aquaculture systems, using biodegradable fishing gears • Capacity building programs to users	• Food and Agriculture Organization (FAO) • United Nations Environment program (UNEP) • United Nations Development Program (UNDP) • Intergovernmental Commission for Oceans (IOC-UNESCO) • World Wildlife Fund (WWF) • World Conservation Society (WCS) • Western Indian Ocean Marine Science Association (WIOMSA) • IOC-Africa • Nairobi Convention • USAID funds - Heshimu Bahari (Respect the Ocean) project in Tanzania	• Challenge 2 which focuses on protecting and restoring ecosystems and biodiversity • Climate change in challenge 5 is crucial for sustainable fisheries • Challenge 10 which relies on communities' understanding that ocean resources are limited, exhaustible and highly susceptible to depletion

				● Many others also provide relevant partnerships and collaborations	
Sunanda Manneela	**Tsunami**	● Traditional methods for estimation of tsunamigenic potential of earthquakes ● Tsunami Risk Knowledge ● Optimal observation network ● Early Warning System ● Last mile connectivity ● Enhancing preparedness ● Improving response range to potential threats	● Multi-sensor approach (seismometers, GNSS, Strong Motion Accelerometers, tilt meters etc.) ● W-phase ● Satellite Altimetry ● Backward Ray Tracing using sea-level data ● High-frequency Coastal RADARs ● Real-time tsunami modelling ● High Performance Computing facilities ● SMART cables ● Oil platform Harvests, Ships equipped with GNSS sensors ● Infrasound	● Global coordination among: Ocean Observing DCO, Data sharing DCO, Ocean Prediction DCC, Coastal Resilience DCC, Regional DCCs, GEMS-Ocean, IOC,ICGs. ● Ocean Decade Tsunami Proramm ●	● Decade challenges (1, 2, 5, 6, 8 and 10) are interconnected
Antoine Queval	**Tsunami**	● Identification of potential causes of tsunamis ● Emphasise the role of landslides ● Volcanoes ● Enhancing detection system	● Advancements in sensor technology ● Integration of seismometers, accelerometers, and pressure sensors into submarine telecommunication cables	● Development of sensor-equipped nodes and their integration into existing telecom systems ● Funding ● Ocean decade tsunami programme	●

			● Deployment and availability		
Giovanni Coppini	**Oil Spills**	● New and better monitoring techniques ● Improved numerical models with higher spatial-temporal resolution and specific coastal parametrizations ● Integration of marine pollution models and observation ● AI methods to improve monitoring, forecasting and risk mapping ● Products on friendly web-based platforms to provide useful information for the local coastal managers and policy makers; and ● Synthesis metrics or indicators tailored for specific sectoral needs	● Cost-effective monitoring technology ● Relocatable modelling and Digital twin ● Cloud computing, HPC ● Satellite and in situ integrated monitoring ● Numerical models with higher spatial-temporal resolution and specific coastal parametrizations ● Data assimilation techniques ● AI methods ● Web-based platforms ● Value added products ● Synthesis metrics	● `Satellite industry ● Funding ● Collaborative frameworks	● Challenges 1, 2, 3, 4, 7 and 8
Andrea Valentini	**Wastewater System**	**Wastewaters treated to a high standard for:** ● Protecting public health: Safe water for swimming and Safe seafood ● Protecting marine ecosystem ● Reduction of pollution	● cutting-edge technologies ● Disruptive solutions ● Decentralized treatment systems ● Smart sensor networks ● Realtime monitoring systems	● International cooperation ● Government for developing, implementing policies and regulations ● Academic and research institutions ● Technical expertise	● Challenges 1,4 and 5

		• Economic resilience to develop solutions	• Early warning and decision support systems • Nature-based solutions • Green infrastructure including construction wetlands and rain gardens • Advances in AI and ML • Adherence to the principles of circular economy	• Private sector, industry expertise • Funding institutions • Public-private partnerships	

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United Nations Decade of Ocean Science for Sustainable Development (2021-2030)

Proclaimed in 2017 by the United Nations General Assembly, the UN Decade of Ocean Science for Sustainable Development (2021-2030), provides a convening framework to develop the scientific knowledge and partnerships needed to catalyse transformative ocean science solutions for sustainable development, connecting people and our ocean. The Ocean Decade is coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC).

Established during the Preparatory Phase and to continue throughout implementation until 2030, the IOC's Ocean Decade Series will provide key documentation about this global initiative and aims to serve as a primary resource for stakeholders seeking to consult, monitor and assess progress towards the vision and mission of the Ocean Decade.

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

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